CEMENTED CARBIDE BLANK SUITABLE FOR ELECTRIC DISCHARGE MACHINING AND CEMENTED CARBIDE BODY MADE BY ELECTRIC DISCHARGE MACHINING

BACKGROUND OF THE INVENTION

[0001] The present invention pertains to a cemented carbide blank that is suitable for electric discharge machining (EDM), as well as a cemented carbide body made by an EDM process from the cemented carbide blank. More specifically, the present invention pertains to a cemented tungsten carbide blank, as well as a cemented tungsten carbide body made by an EDM process from the cemented tungsten carbide blank, that has a cobalt-based binder wherein the cemented carbide blank contains additives of chromium and molybdenum, and in some cases nickel. The cemented tungsten carbide blank is suitable for EDM, and especially prolonged EDM in excess of 30 hours and even in excess of 100 hours and even still in excess of 500 hours, wherein the exposed surface is essentially free of defects caused by electrolytic corrosion or the EDM process.

[0002] Very basically, electric discharge machining (EDM) is a process for making a body that typically has a complex shape. An electrode (e.g., a wire) is positioned near the blank (or body) to be subjected to EDM and the electrode and the blank are placed at different electrical potentials. A controlled electric spark travels between the electrode and the blank that causes the blank to be eroded or explosively evaporated and thereby cut or shaped into the desired configuration. It is typical that the electrode and the blank are located within a liquid dielectric solution. EDM is a very precise method of machining and can be used to make finished bodies of complex shapes. Exemplary products that can be made by EDM include stamping dies and stamping punches.

[0003] Cemented carbides (e.g., cobalt cemented tungsten carbide) have many advantageous properties so that for some applications, it would be desirable to be able to use EDM to shape a cemented carbide body. While EDM has been used to shape cemented carbides such as, for example, a cobalt cemented

tungsten carbide, there have been some drawbacks. In this regard, heretofore, the surface of an EDM finished cemented carbide body has experienced "pitting" wherein holes appear in the surface of the body. The EDM finished cemented carbide body can also experience pitting or corrosion of material underneath (and near to) the surface. The EDM finished cemented carbide body may also experience cracking caused by the EDM process. The EDM finished cemented carbide body may also suffer a decrease in the strength of the material.

[0004] It appears that there is an electrochemical corrosion phenomena that takes place so as to remove by corrosion the binder material (e.g., cobalt in the case of a cobalt cemented tungsten carbide body) from the body so as to create these surface pits or the sub-surface pitting as well as result in the cracking. The presence of the pitting and cracking has also resulted in a decrease in the strength of the body.

[0005] The fact that the surface of the body is subjected to high heat and electrical energy, as well as the fact that the body itself may remain immersed in the dielectric solution for many hours (e.g., up to thirty hours or even one hundred hours or even still up to five hundred hours), accelerates and enhances the electrochemical corrosion of the cobalt binder of the cobalt cemented tungsten carbide body. Thus, it can be appreciated that while the properties of cemented carbides (and especially tungsten carbide-cobalt material) are very advantageous so as to be very applicable for parts of complex shapes, the nature of EDM has inherent drawbacks for use with a material like a tungsten carbide-cobalt alloy.

[0006] U.S. Patent No. 6,514,456 B1 to Lackner et al. pertains to a material that may be subjected to EDM. The Lackner et al. patent appears to disclose a cobalt cemented tungsten carbide alloy that contains one or more additives selected from the group consisting rhenium (Re), germanium (Ge), gallium (Ga), iridium (Ir), osmium (Os), palladium (Pd), silver (Ag), gold (Au), platinum (Pt), tellurium (Te), rhodium (Rh), and ruthenium (Ru). According to

the Lackner et al. patent, the cemented carbide alloy is resistant to “pitting”. Comparative Example 3 of the Lackner et al. patent consists of a cobalt cemented tungsten carbide alloy made by a powder comprising 12 weight percent cobalt, 0.8 weight percent chromium carbide and the balance tungsten carbide. According to the Lackner et al. patent, the chromium carbide was dissolved and the chromium fraction was dissolved in the binder. According to the Lackner et al. patent, this Comparative Example 3 does not exhibit corrosion resistance as good as the corrosion resistance of the composition of the Lackner et al. patent that includes rhenium (Re) that is an additive from the above group (i.e., Re, Ge, Ga, Ir, Os, Pd, Ag, Au, Pt, Te, Rh, and Ru). An article by Lămmle et al. entitled “Hardmetal in the Toolmaking Industry is a question of confidence”, Plansee TIZIT AG, Edition 4, January 2000 pertains to a grade of tungsten carbide-cobalt material that the article says contains chromium and rhenium. According to Lămmle et al., this grade has application for EDM in that it is a grade that is resistant to corrosion and pitting.

[0007] While the Lackner et al. patent and the Lămmle et al. article each says that it discloses an alloy that has resistance to “pitting” as a result of EDM, because “pitting” is an undesirable result, it still remains as a goal to provide a cemented carbide (e.g., tungsten carbide-based material that contains cobalt) that is suitable for EDM without suffering “pitting” or any significant “pitting” as a result of the EDM process. It also remains as a goal to provide a cemented carbide (e.g., tungsten carbide-based material that contains cobalt) that does not suffer any pitting or loss of binder in the surface region underneath the surface of the body as a result of an EDM process. It still further remains as a goal to provide a cemented carbide (e.g., tungsten carbide-based material that contains cobalt) that does not suffer any cracking at the surface as a result of an EDM process. It yet additionally remains as a goal to provide a cemented carbide (e.g., tungsten carbide-based material that contains cobalt) that does not experience a significant reduction in strength as a result of an EDM process.

[0008] The materials disclosed in the Lackner et al. patent use additives (i.e., Re, Ge, Ga, Ir, Os, Pd, Ag, Au, Pt, Te, Rh, and Ru) that are exotic elements in the field of cemented carbides, and especially in the field of cobalt cemented tungsten carbides. The use of these exotic elements as additives in cemented carbides, such as, for example, cobalt cemented tungsten carbide, makes the material more expensive.

[0009] It thus would be highly desirable to provide a cemented carbide (e.g., tungsten carbide-based material that contains cobalt) that does not contain exotic elements (i.e., Re, Ge, Ga, Ir, Os, Pd, Ag, Au, Pt, Te, Rh, and Ru) as additives and that is suitable for EDM without suffering, or at least reducing, "pitting" or any significant "pitting" as a result of the EDM process. It would also be highly desirable to provide a cemented carbide (e.g., tungsten carbide-based material that contains cobalt) that does not contain exotic elements (i.e., Re, Ge, Ga, Ir, Os, Pd, Ag, Au, Pt, Te, Rh, and Ru) as additives and that does not suffer any, or at lest reduces, pitting or loss of binder in the surface region underneath the surface of the body as a result of an EDM process. It further would be highly desirable to provide a cemented carbide (e.g., tungsten carbide-based material that contains cobalt) that does not contain exotic elements (i.e., Re, Ge, Ga, Ir, Os, Pd, Ag, Au, Pt, Te, Rh, and Ru) as additives and that does not suffer any, or at least reduces, cracking at the surface as a result of an EDM process. Finally, it would be highly desirable to provide a cemented carbide (e.g., tungsten carbide-based material that contains cobalt) that does not contain exotic elements (i.e., Re, Ge, Ga, Ir, Os, Pd, Ag, Au, Pt, Te, Rh, and Ru) as additives and that does not experience a significant reduction in strength as a result of an EDM process.

SUMMARY OF THE INVENTION

[0010] In one form thereof the invention is a cemented carbide blank suitable for fabrication by electric discharge machining that includes a carbide phase that includes tungsten carbide (and optionally vanadium carbide) present in an amount equal to between about 77.7 weight percent and about 93.6

weight percent of the cemented carbide blank. The cemented carbide blank further includes chromium present in an amount equal to between about 0.3 weight percent and about 1.5 weight percent of the cemented carbide blank, cobalt present in an amount equal to between about 8 weight percent and about 17 weight percent of the cemented carbide blank, nickel optionally present in an amount equal to 0 weight percent up to about 5 weight percent of the cemented carbide blank, and molybdenum present in an amount equal to between about 0.1 weight percent and about 1.0 weight percent of the cemented carbide blank. The cemented carbide blank having a magnetic saturation as measured according to ASTM B886-03 ranging between about 151 x 10^{-6} T m^3 / kilogram cobalt and about 182 x 10^{-6} T m^3 / kilogram cobalt.

[0011] In another form thereof the invention is a cemented carbide body made by electric discharge machining. The cemented carbide body comprises tungsten carbide (and optionally vanadium carbide) present in an amount equal to between about 77.7 weight percent and about 93.6 weight percent of the cemented carbide blank. The cemented carbide blank further includes chromium present in an amount equal to between about 0.3 weight percent and about 1.5 weight percent of the cemented carbide blank, cobalt present in an amount equal to between about 8 weight percent and about 17 weight percent of the cemented carbide blank, nickel optionally present in an amount equal to 0 weight percent up to about 5 weight percent of the cemented carbide blank, and molybdenum present in an amount equal to between about 0.1 weight percent and about 1.0 weight percent of the cemented carbide blank. The cemented carbide blank having a magnetic saturation as measured according to ASTM B886-03 ranging between about 151 x 10^{-6} T m^3 / kilogram cobalt and about 182 x 10^{-6} T m^3 / kilogram cobalt.

[0012] In one form thereof the invention is a cemented carbide blank suitable for fabrication by electric discharge machining. The cemented carbide blank comprises tungsten carbide present in an amount equal to between about 80 weight percent and about 90.9 weight percent of the cemented carbide

blank. The cemented carbide blank further includes chromium present in an amount equal to between about 0.3 weight percent and about 1.5 weight percent of the cemented carbide blank, cobalt present in an amount equal to between about 8 weight percent and about 14 weight percent of the cemented carbide blank, nickel present in an amount equal to between about 0.7 weight percent and about 1.3 weight percent of the cemented carbide blank, and molybdenum present in an amount equal to between about 0.1 weight percent and about 0.3 weight percent of the cemented carbide blank. The cemented carbide blank has a magnetic saturation as measured according to ASTM B886-03 ranging between about 151 x 10^{-6} T m^3 / kilogram cobalt and about 171 x 10^{-6} T m^3 / kilogram cobalt.

[0013] In another form thereof, the invention is a cemented carbide body made by electric discharge machining. The cemented carbide body comprises tungsten carbide present in an amount equal to between about 80 weight percent and about 90.9 weight percent of the cemented carbide body. The cemented carbide body further includes chromium present in an amount equal to between about 0.3 weight percent and about 1.5 weight percent of the cemented carbide body, cobalt present in an amount equal to between about 8 weight percent and about 14 weight percent of the cemented carbide body, nickel present in an amount equal to between about 0.7 weight percent and about 1.3 weight percent of the cemented carbide body, and molybdenum present in an amount equal to between about 0.1 weight percent and about 0.3 weight percent of the cemented carbide body. The cemented carbide body has a magnetic saturation as measured according to ASTM B886-03 ranging between about 151 x 10^{-6} T m^3 / kilogram cobalt and about 171 x 10^{-6} T m^3 / kilogram cobalt.

[0014] In still another form thereof, the invention is a cemented carbide blank suitable for fabrication by electric discharge machining. The cemented carbide blank comprises a carbide phase present in an amount equal to between about 88.5 weight percent and about 93.6 weight percent of the cemented carbide blank wherein the carbide phase includes tungsten and vanadium and carbon. The cemented carbide blank further includes chromium present in an

amount equal to between about 0.3 weight percent and about 0.9 weight percent of the cemented carbide blank, cobalt present in an amount equal to between about 6 weight percent and about 10 weight percent of the cemented carbide blank, and molybdenum present in an amount equal to between about 0.1 weight percent and about 0.6 weight percent of the cemented carbide blank. The cemented carbide blank has a magnetic saturation as measured according to ASTM B886-03 ranging between about 151 x 10^{-6} T m^3 / kilogram cobalt and about 171 x 10^{-6} T m^3 / kilogram cobalt.

[0015] In yet another form thereof, the invention is a cemented carbide body made by electric discharge machining. The cemented carbide body comprises a carbide phase present in an amount equal to between about 88.5 weight percent and about 93.6 weight percent of the cemented carbide body wherein the carbide phase includes tungsten and vanadium and carbon. The cemented carbide body further includes chromium present in an amount equal to between about 0.3 weight percent and about 0.9 weight percent of the cemented carbide body, cobalt present in an amount equal to between about 6 weight percent and about 10 weight percent of the cemented carbide body, and molybdenum present in an amount equal to between about 0.1 weight percent and about 0.6 weight percent of the cemented carbide body. The cemented carbide body has a magnetic saturation as measured according to ASTM B886-03 ranging between about 151 x 10^{-6} T m^3 / kilogram cobalt and about 171 x 10^{-6} T m^3 / kilogram cobalt.

[0016] In still another form thereof, the invention is a cemented carbide blank suitable for fabrication by electric discharge machining. The cemented carbide blank comprises tungsten carbide present in an amount equal to between about 77.7 weight percent and about 87.9 weight percent of the cemented carbide blank. The cemented carbide blank further includes chromium present in an amount equal to between about 0.4 weight percent and about 1.3 weight percent of the cemented carbide blank, cobalt present in an amount equal to between about 9.5 weight percent and about 15 weight percent of the cemented carbide blank,

nickel present in an amount equal to between about 2 weight percent and about 5 weight percent of the cemented carbide blank, and molybdenum present in an amount equal to between about 0.2 weight percent and about 1.0 weight percent of the cemented carbide blank. The cemented carbide blank has a magnetic saturation as measured according to ASTM B886-03 ranging between about 151 x 10^{-6} T m^3 / kilogram cobalt and about 182 x 10^{-6} T m^3 / kilogram cobalt.

[0017] In yet another form thereof, the invention is a cemented carbide body made by electric discharge machining. The cemented carbide body comprises a body presenting a selected shape. The body comprises tungsten carbide present in an amount equal to between about 77.7 weight percent and about 87.9 weight percent of the cemented carbide body. The cemented carbide body further includes chromium present in an amount equal to between about 0.4 weight percent and about 1.3 weight percent of the cemented carbide body, cobalt present in an amount equal to between about 9.5 weight percent and about 15 weight percent of the cemented carbide body, nickel present in an amount equal to between about 2 weight percent and about 5 weight percent of the cemented carbide body, and molybdenum present in an amount equal to between about 0.2 weight percent and about 1.0 weight percent of the cemented carbide body. The cemented carbide body having a magnetic saturation as measured according to ASTM B886-03 ranging between about 151 x 10^{-6} T m^3 / kilogram cobalt and about 182 x 10^{-6} T m^3 / kilogram cobalt.

[0018] In yet another form thereof the invention is a cemented carbide blank suitable for fabrication by electric discharge machining. The cemented carbide blank comprises tungsten carbide present in an amount equal to between about 81.1 weight percent and about 86.4 weight percent of the cemented carbide blank; chromium present in an amount equal to between about 0.4 weight percent and about 1.3 weight percent of the cemented carbide blank; cobalt present in an amount equal to between about 13 weight percent and about 17 weight percent of the cemented carbide blank; and molybdenum present in an amount equal to between about 0.2 weight percent and about 0.6 weight percent of the

cemented carbide blank. The cemented carbide blank has a magnetic saturation as measured according to ASTM B886-03 ranging between about 151 x 10^{-6} T m^3 / kilogram cobalt and about 182 x 10^{-6} T m^3 / kilogram cobalt.

[0019] In still another form thereof, the invention is a cemented carbide body made by electric discharge machining. The cemented carbide body comprises a body presenting a selected shape. The body comprises tungsten carbide present in an amount equal to between about 81.1 weight percent and about 86.4 weight percent of the cemented carbide blank; chromium present in an amount equal to between about 0.4 weight percent and about 1.3 weight percent of the cemented carbide blank; cobalt present in an amount equal to between about 13 weight percent and about 17 weight percent of the cemented carbide blank; and molybdenum present in an amount equal to between about 0.2 weight percent and about 0.6 weight percent of the cemented carbide blank. The cemented carbide blank having a magnetic saturation as measured according to ASTM B886-03 ranging between about 151 x 10^{-6} T m^3 / kilogram cobalt and about 182 x 10^{-6} T m^3 / kilogram cobalt.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] The following is a brief description of the drawings that form a part of this patent application:

[0021] FIG. 1 is an isometric view of a blank that may be fabricated (or made) into a finished body (or product) by EDM techniques;

[0022] FIG. 2 is a photomicrograph that shows the microstructure of the specific embodiment of Example 1 wherein there is a 10 micrometer (μm) scale;

[0023] FIG. 3 is a photomicrograph of the top surface of the specific embodiment of Example 1 subjected to a rough cut EDM process and wherein there is a 20 micrometer (μm) scale;

[0024] FIG. 4 is a photomicrograph of a cross-section of the surface of the specific embodiment of the invention shown in FIG. 3 (subjected to a rough cut EDM process) wherein there is a 20 micrometer (μm) scale;

[0025] FIG. 5 is a photomicrograph at one location of a cross-section of the surface of the specific embodiment of the invention shown in FIG. 3 (subjected to a rough cut EDM process) wherein there is a 10 micrometer (μm) scale;

[0026] FIG. 6 is a photomicrograph at another location of a cross-section of the surface of the specific embodiment of the invention shown in FIG. 3 (subjected to a rough cut EDM process) wherein there is a 10 micrometer (μm) scale;

[0027] FIG. 7 is a photomicrograph at one location of a cross-section of the surface of the specific embodiment of Example 1 subjected to a fine cut EDM process wherein there is a 10 micrometer (μm) scale;

[0028] FIG. 8 is a photomicrograph at another location of a cross-section of the surface of the specific embodiment of FIG. 7 (subjected to a fine cut EDM process) wherein there is a 20 micrometer (μm) scale;

[0029] FIG. 9 is a corrosion plot that compares the corrosion resistance of the following materials: a standard tungsten carbide-12 weight percent cobalt grade, and a tungsten carbide-cobalt-based alloy made by Plansee TIZIT and sold under the designation CF H40S, and a cemented carbide blank of the specific embodiment of Example 1; and

[0030] FIG. 10 is a photomicrograph that shows the microstructure of a cemented carbide blank of the specific embodiment of Example 3 wherein there is a 10 micrometer (μm) scale.

DETAILED DESCRIPTION OF THE INVENTION

[0031] Referring to the drawings, FIG. 1 shows a cemented carbide blank 20 of material made according to the present invention. This blank 20 may be subjected to EDM so as to fabricate a part (or a cemented carbide body). EDM is a technique that is suitable for the fabrication of parts that have complex shapes so that the present invention provides a material that is applicable to many products including stamping dies and stamping punches. It should also be appreciated that the material of the invention can be used to fabricate components of fluid handling equipment used in the oil, gas and chemical industries. One of these components can be a part of a ball valve assembly, and more particularly, the extreme seat in a ball valve assembly.

[0032] Some applications for hard materials require parts of a complex shape so that EDM is a very suitable process to fabricate the part. However, for a hard material like a tungsten carbide-cobalt alloy EDM may not be a suitable fabrication technique due to the negative effects of electrochemical corrosion of the cobalt from the tungsten carbide-cobalt alloy that occurs during the EDM. However, by the present invention, one can take the basic composition of a hard material (e.g., a cobalt cemented tungsten carbide) that has suitable properties (e.g., hardness or toughness), and modify such composition so as to make it resistant to the electrochemical corrosive effects of EDM, as well as the susceptibility to cracking during the EDM process, so that it can be fabricated by EDM into a finished cemented carbide body that still possesses its desirable properties (e.g., hardness or toughness and the like).

[0033] Example 1 is one specific embodiment of the present invention. Example 1 comprises a tungsten carbide-based material that has a carbide phase that includes tungsten carbide and a cobalt-based binder phase. The tungsten carbide-based material further includes additions of nickel and chromium and molybdenum wherein at least some of these additions (i.e., nickel and chromium and molybdenum) are present in the binder phase. Example 1 is made

by powder metallurgical techniques. The starting powder mixture comprises: about 85.8 weight percent tungsten carbide wherein the tungsten carbide has a particle size equal to 1 to 4 micrometers (μm), about 1.0 weight percent chromium carbide (equals about 0.9 weight percent chromium), about 10.8 weight percent cobalt, about 1.0 weight percent nickel, about 1.2 weight percent tungsten, and about 0.2 weight percent molybdenum.

[0034] This starting powder mixture was ball milled for between about 6 hours to about 8 hours. The ball-milled powder mixture was then pressed into a green compact. The green compact was then dewaxed at a temperature between about 400 degrees Centigrade and about 650 degrees Centigrade. The dewaxed compact was then sintered under the following conditions: a temperature equal to about 1405 degrees Centigrade for about 60 minutes in a vacuum to form a sintered body. The sintered body was then hot isostatically pressed under the following conditions: a temperature equal to about 1405 degrees Centigrade at a pressure equal to 450 pounds per square inch (psi) (3.1 MPa) in argon gas for 30 minutes to form the consolidated cemented carbide blank.

[0035] The consolidated cemented carbide blank of Example 1 is a tungsten carbide-based cobalt alloy that contains chromium and nickel and molybdenum. The cemented carbide blank of Example 1 has the following composition (wherein the weight percent is of the entire consolidated cemented carbide blank): about 87.1 weight percent tungsten carbide, about 0.9 weight percent chromium, abut 10.8 weight percent cobalt, about 1.0 weight percent nickel, and about 0.2 weight percent molybdenum. The cemented carbide blank of Example 1 has the following properties: a density of about 14.2 ± 0.1 grams per cubic centimeter, a coercive force (H_C) measured in oersteds of about 170, a Rockwell A hardness equal to about 90.0 ± 0.4, a magnetic saturation equal to between about to 151 x 10^{-6} T m^3 / kilogram cobalt and about to 171 x 10^{-6} T m^3 / kilogram cobalt, a porosity of about A02B00C00, and a transverse rupture strength equal to about 3500 ± 200 MPa.

[0036] The properties for Example 1, as well as those for Examples 2 through 4 set forth hereinafter, were determined per the various ASTM standards (ASTM International, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428, USA) set forth below. The density was measured according to the procedure set forth in ASTM B311-93(2000) (Test Method for Density Determination for Powder Metallurgy (Materials Containing Less Than Two Percent Porosity)). The coercive force was measured according to the procedure set forth in ASTM Standard B887-03 (Standard Test Method for Determination of Coercivity (H_{CS}) of Cemented Carbides). The Rockwell A hardness was measured according to the procedure set forth in ASTM Standard B294-92 (2001) (Standard Test Method for Hardness Testing of Cemented Carbides). The magnetic saturation was measured according to the procedure set forth in ASTM Standard B886-03 (Standard Test Methods for Determination of Magnetic Saturation (M_S) in Cemented Carbides). The porosity was determined according to the procedure set forth in ASTM B276-91(2000) (Standard Test Method for Apparent Porosity in Cemented Carbides) . The transverse rupture strength was measured according to the procedures set forth in ASTM Standard B406-96(2000) (Standard Test Method for Transverse Rupture Strength of Cemented Carbides).

[0037] A visual examination (at 200X) of the etched microstructure showed that there was an absence of eta phase from the consolidated cemented carbide blank of Example 1.

[0038] As previously discussed, the consolidated cemented carbide blank may be subjected to EDM so as to form the EDM finished product.

[0039] In regard to the components of the starting powder mixture for Example 1, it should be appreciated that the tungsten carbide component may also comprise in whole or in part macrocrystalline tungsten carbide. U.S. Patent No. 3,379,503 to McKenna and U.S. Patent No. 4,834,963 to Terry et al. disclose macrocrystalline tungsten carbide and processes to make the same. It should be

appreciated that although the starting powder mixture of Example 1uses chromium carbide to contribute chromium to the mixture, one could use chromium metal in the appropriate amount (e.g., for Example 1 the chromium component would equal about 0.9 weight percent).

[0040] In further regard to the components of the starting powder mixture of Example 1, the components of the starting powder may fall within the following range that comprises: between about 84.2 weight percent and about 90.1 weight percent tungsten carbide, between about 0.4 weight percent and about 1.2 weight percent chromium carbide (or chromium equal to between about 0.3 weight percent and about 1 weight percent), between about 8 weight percent and about 11 weight percent cobalt, between about 0.7 weight percent and about 1.3 weight percent nickel, 0 weight percent to about 2 weight percent tungsten, and between about 0.1 weight percent and about 0.3 weight percent molybdenum.

[0041] In regard to the process parameters used to make Example 1, it should be appreciated that the sintering parameters may be within the following ranges: a temperature range between about 1360 degrees Centigrade and about 1500 degrees Centigrade (and an alternate temperature range between ranging between about 1400 degrees Centigrade and about 1450 degrees Centigrade) for a duration ranging between about 60 minutes to about 90 minutes in a vacuum. It should be appreciated that the hot isostatic pressing parameters may be within the following ranges: a temperature range of between about 1360 degrees Centigrade and about 1500 degrees Centigrade (and an alternate range between ranging between about 1400 degrees Centigrade and about 1450 degrees Centigrade) and a pressure range between about 80 psi and higher (and an alternate pressure range between about 300 psi and about 800 psi) for a duration between about 60 minutes and about 120 minutes.

[0042] Applicant contemplates that a consolidated cemented carbide blank along the lines of Example 1 may have the following range of composition (wherein the weight percent is of the entire consolidated cemented

carbide blank): between about 80 weight percent and about 90.9 weight percent tungsten carbide, between about 0.3 weight percent and about 1.5 weight percent chromium, between about 8 weight percent and about 14 weight percent cobalt, between about 0.7 weight percent and about 1.3 weight percent nickel, and between about 0.1 weight percent and about 0.3 weight percent molybdenum. An alternate range of composition (wherein the weight percent is of the entire consolidated cemented carbide blank) comprises: between about 85 weight percent and about 90.9 weight percent tungsten carbide, between about 0.3 weight percent and about 1.1 weight percent chromium, between about 8 weight percent and about 11 weight percent cobalt, between about 0.7 weight percent and about 1.3 weight percent nickel, and between about 0.1 weight percent and about 0.3 weight percent molybdenum. Yet, another alternate range of composition (wherein the weight percent is of the entire consolidated cemented carbide blank) comprises between about 85.4 weight percent and about 88.4 weight percent tungsten carbide, between about 0.6 weight percent and about 1.2 weight percent chromium, between about 10 weight percent and about 12 weight percent cobalt, between about 0.9 weight percent and about 1.1 weight percent nickel, and between about 0.1 weight percent and about 0.3 weight percent molybdenum.

[0043] In regard to the relation between the cobalt, chromium, nickel, and molybdenum, in one range, the chromium comprises between about 1.9 weight percent and about 14 weight percent of the sum of the elements cobalt and chromium and nickel and molybdenum, the nickel comprises between about 4.3 weight percent and about 14.4 weight percent of the sum of the elements cobalt and chromium and nickel and molybdenum, and the molybdenum comprises between about 0.6 weight percent and about 3.3 weight percent of the sum of the elements cobalt and chromium and nickel and molybdenum. In another range, the chromium comprises between about 4.3 weight percent and about 10 weight percent of the sum of the elements cobalt and chromium and nickel and molybdenum, the nickel comprises between about 6.4 weight percent and about 9.2 weight percent of the sum of the elements cobalt and chromium and

nickel and molybdenum, and the molybdenum comprises between about 0.6 weight percent and about 3.3 weight percent of the sum of the elements cobalt and chromium and nickel and molybdenum.

[0044] In regard to the range of the properties of a consolidated cemented tungsten carbide blank using a starting powder mixture of Example 1 within the above ranges, the blank has the following range of properties: a density between about 13.9 and about 14.6 grams per cubic centimeter, a coercive force (H_C) measured in oersteds between about 110 and about 170, a Rockwell A hardness between about 88 and about 90, a magnetic saturation between about 151 10^{-6} T m^3 / kilogram cobalt and about 182 10^{-6} T m^3 / kilogram cobalt, and a porosity better than or equal to A06 B02 C00.

[0045] The microstructure of the consolidated cemented carbide blank of Example 1 is shown in FIG. 2. As can be seen, the consolidated cemented carbide blank has a relatively fine-grained microstructure.

[0046] The consolidated cemented carbide blank of Example 1 was subjected to a so-called "rough cut" wire EDM under the following conditions: faster cut at about 20 volts. FIGS. 3 through 6 shows the surface region of the finished cemented carbide body of Example 1 after being subjected to the rough cut EDM as described above. The microstructure shown in FIGS. 3 through 6 may be considered to be essentially free of defects caused by EDM in the case of a rough cut EDM process.

[0047] FIG. 3, which has a 20 micrometer (μm) scale, showed only a small pit (i.e., a dimension of about 10 micrometers (μm)). The rest of the surface of the finished body had a clean appearance. The examination showed only a total of six pits over the entire surface area (about 4 inches (about 10.2 centimeters) by about 0.5 inches (about 1.3 centimeters) of the finished body.

[0048] FIG. 4 shows a cross-sectional photomicrograph of the surface region of the cemented carbide body of Example 1 that resulted from the

above-described rough cut EDM. At this scale it can be seen that the surface region was free of pitting and did not show the effects of any electrochemical corrosion. FIGS. 5 and 6 are photomicrographs that also show in cross section the surface region of the cemented carbide body of Example 1 that resulted from the above-described rough cut EDM. It can be seen at this scale that there was some pitting either at the surface or in the surface region of the cemented carbide body underneath the surface.

[0049] The consolidated cemented carbide blank of Example 1 was subjected to a so-called "fine cut" wire EDM under the following conditions: slower cut at about 10 volts. FIGS. 7 and 8 show in cross-section the surface region of the cemented carbide body of Example 1 that resulted from the EDM fine cut as described above. As can be seen from these photomicrographs, the surface region of this body of Example 1 did not suffer any effects of electrochemical corrosion such as, for example, pitting at the surface or pitting in the surface region beneath the surface. The microstructure shown in FIGS. 7 and 8 may be considered to be essentially free of defects caused by EDM in the case of a fine cut EDM process.

[0050] An examination of the finished cemented carbide body of Example 1 that was the result from the fine cut EDM process shows that this material of Example 1 exhibited excellent corrosion resistance. Example 1 did not present severe pitting at the surface. The material of Example 1 did not suffer the pitting and corrosion in the surface region beneath the surface. The material of Example 1 did not experience the cracking caused by the EDM process. The material of Example 1 did not experience a significant loss in strength wherein after EDM it retained at least between about 50 percent to 60 percent of the original strength. It can thus be seen that the finished consolidated cemented carbide body of Example 1 is a material that is able to satisfactorily withstand electrochemical corrosion that occurs during a fine cut EDM process.

[0051] Referring to FIG. 9, the cemented carbide blank of Example 1 was tested against a tungsten carbide-cobalt-based material made and sold by Plansee TIZIT under the designated CF H40S and a standard tungsten carbide-12 weight percent cobalt grade to determine the relative resistance to electrochemical corrosion of these materials. According to analyses by the assignee of the present patent application (i.e., Kennametal Inc.), the Plansee CF-H40S grade of material has the following composition and properties. The basic composition is about 11.7 weight percent cobalt, about 1.0 weight percent chromium, about 0.04 weight percent molybdenum, about 0.07-0.085 weight percent iron and about 0.04 weight percent titanium and the balance tungsten carbide. Kennametal Inc.'s analysis did not analyze the material for rhenium, but according to the heretofore-mentioned article by Lămmle et al. entitled "Hardmetal in the Toolmaking Industry is a question of confidence", this Plansee grade contains chromium and rhenium. Per Kennametal Inc.'s analyses, the properties comprise a porosity of A02 B00 C00, a tungsten carbide grain size of 1-5 micrometers, a magnetic saturation equal to 161-175 x 10^{-6} T m^3/ kilogram cobalt, a coercive force (H_C) equal to 136-139 oersteds, a Rockwell A hardness equal to 90.3-90.4 HRA, a Vickers Hardness (30 kilogram load) equal to 1448 ± 6, and a density equal to 14.11-14.14 grams per cubic centimeter.

[0052] The lines in FIG. 9 are labeled "EXAMPLE 1" to refer to the cemented carbide blank of Example 1, "CF-H40S" to refer to the Plansee grade, and "WC-12 wt% Co" to refer to the standard grade that comprises about 12 weight percent cobalt and about 88 weight percent tungsten carbide. Electrochemical corrosion is the kind of corrosion that a material is exposed to during EDM. The test procedure standard to determine the resistance to electrochemical corrosion is ASTM G5-94(1999)e1 entitled "Standard Reference Test Method for Making Potentiostatic and Potentiodynamic Anodic Polarization Measurements".

[0053] This test per ASTM G5-94(1999)e1 is an accelerated test. It is based on the principle that corrosion is an oxidation process by which

electrons are released from the corroded specimen. In the electrochemical cell (i.e., that flask (or container) with the corroding solution therein), a voltage is applied between the anode (the specimen) and the cathode (graphite rods), and the current that is generated as a result is then measured. In this test, the corroding solution was 0.1 N hydrochloric acid. The measured current is a measure or a reflection of the corrosion rate of a material.

[0054] A plot such as shown in FIG. 9 is generated as a result of the testing. The x-axis of the plot is the applied potential across the anode (specimen) and the cathode (graphite rod). This applied potential is measured in E (mv). This figure is a measure of the intensity of the corrosive environment. The y-axis is a logarithm of the current generated in the external circuit as a result of the applied potential difference. The specific current is measured in A/m^2. This figure is a measure of the corrosion rate of the specimen.

[0055] As can be seen in FIG. 9, the plot has two branches that are separated by a vertical line. The position of the vertical line is indicative of the inherent nobility of the material. In a comparison on the two plots (i.e., a plot of the Plansee material and a plot of the Example 1 material), the material that has its plot that has the vertical line on the farther right is more noble than the other material. FIG. 9 shows that one specific embodiment of the invention, i.e., the consolidated cemented carbide blank of Example 1, exhibits a corrosion rate that was about 20 to about 30 times lower as compared to the Plansee material.

[0056] The right-side horizontal branch (i.e., the anodic part) is indicative of the corrosion rate and the type. The lower the line represents the lower the current and the lower corrosion rate. A drop in the corrosion current is indicated by a depression in the anodic part is indicative of passivation where a protective layer is formed on the surface of the material.

[0057] Example 2 is another specific embodiment of the invention. Example 2 was made using the following starting powder mixture: about 91.2 weight percent tungsten carbide (the particle size of the tungsten carbide is about

0.4 to about 0.6 micrometers (μm)), about 8.0 weight percent cobalt, about 0.5 weight percent chromium carbide (Cr_3C_2), about 0.1 weight percent vanadium carbide, about 0.5 weight percent tungsten, and about 0.2 weight percent molybdenum. This powder mixture was attritor milled in heptane using cemented carbide balls for about 6 hours.

[0058] The powder mixture was then pressed into a green compact. The green compact was de-waxed at a temperature between about 400 degrees Centigrade and about 650 degrees Centigrade. The de-waxed compact was then sintered at 1405 degrees Centigrade for 60 minutes in a vacuum followed by hot isostatic pressing at a temperature of about 1405 degrees Centigrade and a pressure equal to about 450 pounds per square inch (3.1 MPa) in argon gas for a duration equal to about 30 minutes.

[0059] The consolidated cemented carbide blank of Example 2 has the following composition: about 91.3 weight percent tungsten carbide (the particle size of the tungsten carbide is about 0.4 to about 0.6 micrometers (μm)), about 0.1 weight percent vanadium carbide that applicant believes is in solid solution with the tungsten carbide, about 8.0 weight percent cobalt, about 0.4 weight percent chromium, and about 0.2 weight percent molybdenum. The binder is cobalt-based and applicant believes that the binder contains at least some of the chromium and molybdenum.

[0060] The consolidated cemented carbide blank of Example 2 has properties that fall within the following ranges: a density equal to between about 14.5 and about 14.8 grams per cubic centimeter, a coercive force (Hc) measured in oersteds between about 260 and about 310, a Rockwell A hardness equal to about 92.5 and about 93, a magnetic saturation equal to between about 151 x 10^{-6} T m^3 / kilogram cobalt and about to 171 x 10^{-6} T m^3 / kilogram cobalt, a transverse rupture strength (TRS) equal to between about 3500 MPa and about 3700 MPa, and a porosity of A02B00C00. A visual examination (200X) showed that there was no eta phase present in the microstructure.

[0061] The consolidated cemented carbide blank of Example 2 is suitable to be subjected to EDM so as to form an EDM finished cemented carbide body.

[0062] In regard to the starting components for Example 2, applicant contemplates that the components of the starting powder mixture may fall within the following range (weight percent of the starting powder mixture): between about 90 weight percent and about 94 weight percent tungsten carbide, between about 0.5 weight percent and about 1.0 weight percent chromium carbide (in the case of an addition of chromium metal, between about 0.4 weight percent and about 0.9 weight percent chromium), between about 6 weight percent and about 10 weight percent cobalt, up to about 0.3 weight percent vanadium carbide, 0 weight percent to about 1 weight percent tungsten, and between about 0.1 weight percent and about 0.6 weight percent molybdenum. A consolidated cemented carbide blank made with a starting powder mixture within the above range has the following range of composition (weight percent of the cemented carbide blank): between about 90.1 weight percent and about 93.6 weight percent tungsten carbide (the particle size of the tungsten carbide is about 0.4 to about 0.6 micrometers (μm)), up to about 0.3 weight percent vanadium carbide wherein applicant believes that the vanadium carbide is in solid solution with the tungsten carbide, between about 6 weight percent and about 10 weight percent cobalt, between about 0.3 weight percent and about 0.9 weight percent chromium, and between about 0.1 weight percent and about 0.6 weight percent molybdenum. The cemented carbide blank has a binder phase that includes at least some of the cobalt, chromium and molybdenum.

[0063] In regard to the relationship of the components of the elements cobalt, chromium and molybdenum, in one range the chromium comprises between about 3 weight percent and about 15.8 weight percent of the sum of the cobalt and chromium and molybdenum, and the molybdenum comprises between about 1 weight percent and about 10.5 weight percent of the sum of the cobalt and chromium and molybdenum. In another range, the

chromium comprises between about 3 weight percent and about 8 weight percent of the sum of the cobalt and chromium and molybdenum, and the molybdenum comprises between about 1 weight percent and about 5 weight percent of the sum of the cobalt and chromium and molybdenum.

[0064] Applicant contemplates that a consolidated cemented carbide blank along the lines of Example 2 can have properties within the following range: a density between about 13.9 and about 14.6 grams per cubic centimeter, a coercive force (H_C) measured in oersteds between about 250 and about 350, a Rockwell A hardness between about 92 and about 93.5, a magnetic saturation between about 171 x 10^{-6} T m^3 / kilogram cobalt and about to 182 x 10^{-6} T m^3 / kilogram cobalt, and a porosity that is better than or equal to A04B00C00.

[0065] In regard to the process parameters to make the consolidated cemented carbide blank of Example 2, the sintering parameters and the hot isostatic pressing parameters fall within the ranges set forth above for Example 1.

[0066] The consolidated cemented carbide blank of Example 3 is another specific embodiment of the invention wherein Example 3 is made using the following starting powder mixture: about 84.6 weight percent tungsten carbide (the particle size of the tungsten carbide is about 4 to about 7 micrometers (μm)), about 10 weight percent cobalt, about 3 weight percent nickel, about 1 weight percent chromium carbide (Cr_3C_2), about 1.2 weight percent tungsten, and about 0.2 weight percent molybdenum. This powder mixture was attritor milled in heptane using cemented carbide balls for about 6 hours.

[0067] The powder mixture is then pressed into a green compact. The green compact was de-waxed at a temperature between about 400 degrees Centigrade and about 650 degrees Centigrade. The de-waxed compact was then sintered at 1405 degrees Centigrade for 60 minutes in a vacuum followed by hot isostatic pressing at a temperature of about 1405 degrees Centigrade and a pressure equal to about 450 pounds per square inch (3.1 MPa) in argon gas for a

duration equal to about 30 minutes so as to form a consolidated cemented carbide blank. The consolidated cemented carbide blank of Example 3 may be subjected to EDM so as to form the EDM finished cemented carbide body.

[0068] The consolidated cemented carbide blank of Example 3 has the following composition: about 85.9 weight percent tungsten carbide (the particle size of the tungsten carbide is about 4 to about 7 micrometers (μm)), about 10 weight percent cobalt, about 3 weight percent nickel, about 0.9 weight percent chromium, and about 0.2 weight percent molybdenum.

[0069] The consolidated cemented carbide blank of Example 3 has the following properties: a density equal to about 14.2 ± 0.5 grams per cubic centimeter, a coercive force (Hc) measured in oersteds equal to about 120 ± 20, a Rockwell A hardness equal to about 88.4 ± 0.5 HRA, a magnetic saturation equal to 151 x 10^{-6} T m^3 / kilogram cobalt and about to 181 x 10^{-6} T m^3 / kilogram cobalt, a transverse rupture strength (TRS) equal to between about 3200 and about 3400 MPa, and a porosity equal to A02B00C00. A visual examination at 200X showed that eta phase was not present in the microstructure.

[0070] In regard to the starting components for Example 3, applicant contemplates that the components of the starting powder may fall within the following range (weight percent of the starting powder mixture): between about 80 weight percent and about 90 weight percent tungsten carbide, between about 0.5 weight percent and about 1.5 weight percent chromium carbide (in the case of an addition of chromium metal, between about 0.4 weight percent and about 1.3 weight percent chromium), between about 9.5 weight percent and about 15 weight percent cobalt, between about 2 weight percent and about 5 weight percent nickel, 0 weight percent to about 1.5 weight percent tungsten, and between about 0.2 weight percent and about 1.0 weight percent molybdenum. Applicant contemplates that a consolidated cemented carbide blank made with a powder mixture within the above range would have a composition (weight percent of the cemented carbide blank) comprising between about 80.1 weight percent and

about 90.2 weight percent tungsten carbide, between about 0.4 weight percent and about 1.3 weight percent chromium, between about 9.5 weight percent and about 15 weight percent cobalt, between about 2 weight percent and about 5 weight percent nickel, and between about 0.2 weight percent and about 1.0 weight percent molybdenum.

[0071] The relationship between the elements cobalt, chromium, nickel and molybdenum has the following range: the chromium comprises between about 2 weight percent and about 10 weight percent of the sum of the cobalt and chromium and nickel and molybdenum, the nickel comprises between about 10 weight percent and about 33 weight percent of the sum of the cobalt and chromium and nickel and molybdenum, and the molybdenum comprises between about 1 weight percent and about 7.8 weight percent of the sum of the cobalt and chromium and nickel and molybdenum.

[0072] Applicant contemplates that a consolidated cemented carbide blank along the lines of Example 3 can have properties within the following range: a density between about 13.8 and about 14.5 grams per cubic centimeter, a coercive force (H_C) measured in oersteds between about 80 and about 150, a Rockwell A hardness between about 85 and about 89, a magnetic saturation between 151 x 10^{-6} T m^3 / kilogram cobalt and about to 182 x 10^{-6} T m^3 / kilogram cobalt, and a porosity better than or equal to A06 B02 C00.

[0073] In regard to the ranges for the process parameters to make Example 3, the sintering parameters and the hot isostatic pressing parameters fall within the ranges set forth above for Example 1.

[0074] Another specific embodiment of the invention is Example 4. Example 4 is a cobalt cemented tungsten carbide material made from the following starting powder mixture (weight percent of the starting powder mixture): about 82.8 weight percent tungsten carbide (the particle size of the tungsten carbide is about .8 to about 1.0 micrometers (μm)), about 15 weight percent cobalt, about 0.8 weight percent chromium carbide (Cr_3C_2), about 1.2

weight percent tungsten, and about 0.2 weight percent molybdenum. This powder mixture was attritor milled in heptane using cemented carbide balls for about 6 hours.

[0075] The powder mixture is then pressed into a green compact. The green compact was de-waxed at a temperature between about 400 degrees Centigrade and about 650 degrees Centigrade. The de-waxed compact was then sintered at 1405 degrees Centigrade for 60 minutes in a vacuum followed by hot isostatic pressing at a temperature of about 1405 degrees Centigrade and a pressure equal to about 450 pounds per square inch (3.1 MPa) in argon gas for a duration equal to about 30 minutes so as to form a consolidated cemented carbide blank. The consolidated cemented carbide blank of Example 4 may be subjected to EDM so as to form the EDM finished cemented carbide body.

[0076] The consolidated cemented carbide blank of Example 4 has the following composition (weight percent of the cemented carbide blank): about 84.1 weight percent tungsten carbide (the particle size of the tungsten carbide is about .8 to about 1.2 micrometers (μm)), about 15 weight percent cobalt, about 0.7 weight percent chromium, and about 0.2 weight percent molybdenum.

[0077] The consolidated cemented carbide blank of Example 4 has the following properties: a density equal to about 13.97 ± 0.5 grams per cubic centimeter, a coercive force (Hc) measured in oersteds equal to about 208 ± 20, a Rockwell A hardness equal to about 89.8 ± 0.5 HRA, a magnetic saturation equal to 160 x 10^{-6} T m^3 / kilogram cobalt, a transverse rupture strength (TRS) equal to about 4000 ± 200 MPa, and a porosity equal to better than or equal to A02B00C00. A visual examination at 200X showed that eta phase was not present in the microstructure.

[0078] In regard to the starting components for Example 4, applicant contemplates that the components of the starting powder may fall within the following one range (weight percent of the starting powder mixture): between about 78.9 weight percent and about 85.5 weight percent tungsten carbide,

between about 0.5 weight percent and about 1.5 weight percent chromium carbide (when added in the form chromium between about 0.4 and about 1.3 weight percent chromium), between about 13 weight percent and about 17 weight percent cobalt, 0 weight percent to about 2.0 weight percent tungsten, and between about 0.2 weight percent and about 0.6 weight percent molybdenum. Applicant contemplates that a consolidated cemented carbide body made with a powder mixture within the above range would have a composition comprising between about 81.1 weight percent and about 86.4 weight percent tungsten carbide, between about .4 weight percent and about 1.3 weight percent chromium, between about 13 weight percent and about 17 weight percent cobalt, and between about .2 weight percent and about .6 weight percent molybdenum.

[0079] The relationship between the elements cobalt, chromium, and molybdenum has the following range: the chromium comprises between about 2 weight percent and about 10 weight percent of the sum of the cobalt and chromium and molybdenum, and the molybdenum comprises between about 1 weight percent and about 4.4 weight percent of the sum of the cobalt and chromium and molybdenum.

[0080] Applicant contemplates that a consolidated cemented carbide blank along the lines of Example 4 can have properties within the following range: a density between about 13.7 and about 14.3 grams per cubic centimeter, a coercive force (H_C) measured in oersteds between about 180 and about 230, a Rockwell A hardness between about 88 and about 90, a magnetic saturation between 151 x 10^{-6} T m^3 / kilogram cobalt and about to 182 x 10^{-6} T m^3 / kilogram cobalt, and a porosity better than or equal to A04 B00 C00.

[0081] In regard to the ranges for the process parameters to make Example 4, the sintering parameters and the hot isostatic pressing parameters fall within the ranges set forth above for Example 1.

[0082] Referring to the material of the invention in general, in regard to the relationship between the elements cobalt, chromium, nickel and

molybdenum, applicant contemplates that in one range the cobalt will comprise between about 80 weight percent and about 95 weight percent of the sum of the cobalt, chromium, nickel and molybdenum. The sum of the chromium, nickel and molybdenum will comprise between about 5 weight percent and about 20 weight percent of the sum of the cobalt, chromium, nickel and molybdenum. In another ratio of the elements cobalt, chromium, nickel and molybdenum, applicant contemplates that the cobalt will comprise about 90 weight percent of the sum of the cobalt, chromium, nickel and molybdenum and that the chromium, nickel and molybdenum will comprise about 10 weight percent of the sum of the cobalt, chromium, nickel and molybdenum.

[0083] In forming the consolidated body, it is important that the chromium disassociated from the carbon in the chromium carbide additive remains free in the cobalt binder alloy and does not recombine with the carbon. This is because during the EDM process, the free chromium combines with oxygen to form chromium oxide. The chromium oxide is a protective layer that retards or eliminates the electrolytic corrosion due to the EDM process. The chromium oxide layer increases the passivity of the material.

[0084] In order to facilitate the presence of free chromium and reduce the possibility that the chromium will recombine with the carbon, tungsten (in addition to the tungsten in the tungsten carbide) is added to the starting powder mixture. At least some of this additional tungsten metal is present in the binder and combines with the disassociated carbon from the chromium carbide to eliminate free carbon that could combine with the chromium. There does not appear to be any free carbon in the binder. The presence of tungsten in the cobalt binder is measured by the magnetic saturation of the tungsten carbide-cobalt alloy. It has been found that the magnetic saturation should be between about 75 percent and about 90 percent wherein 100 percent is equal to 201 x 10^{-6} T m^3 / kilogram cobalt, i.e., the magnetic saturation should range between about to 151 x 10^{-6} T m^3 / kilogram cobalt and about to 182 x 10^{-6} T m^3 / kilogram cobalt. See Santhanam et al., "Cemented Carbides", Metals Handbook, Volume 16, 9th Edition, (1989),

Machining ASM International, pages 71-89.

[0085] It is preferred that eta (η) phase (i.e., double carbides such as Co_3W_3C and Co_6W_6C) not be present in the material.

[0086] The presence of molybdenum on the consolidated cemented carbide blank improves the resistance of the consolidated blank to pitting due to electrochemical corrosion. The presence of molybdenum on the consolidated cemented carbide blank improves the toughness of the consolidated blank.

[0087] It can thus be seen that applicant has invented a new and useful cemented carbide blank, as well as a cemented carbide body made from the cemented carbide blank by an EDM process. The cemented carbide blank of the invention provides a cemented carbide (e.g., tungsten carbide-based material that contains cobalt) that does not contain exotic elements additives (i.e., Re, Ge, Ga, Ir, Os, Pd, Ag, Au, Pt, Te, Rh, and Ru) as additives and is suitable for EDM without suffering, or at least reduces, "pitting" or any significant "pitting" as a result of the EDM process. The cemented carbide blank of the invention also provides a cemented carbide (e.g., tungsten carbide-based material that contains cobalt) that does not contain exotic elements additives (i.e., Re, Ge, Ga, Ir, Os, Pd, Ag, Au, Pt, Te, Rh, and Ru) as additives and does not suffer any, or at least reduces, pitting or loss of binder in the surface region underneath the surface of the body as a result of an EDM process. The cemented carbide blank of the invention also provides a cemented carbide (e.g., tungsten carbide-based material that contains cobalt) that does not contain exotic elements additives (i.e., Re, Ge, Ga, Ir, Os, Pd, Ag, Au, Pt, Te, Rh, and Ru) as additives and does not suffer any, or at least reduces, cracking at the surface as a result of an EDM process. Finally, the cemented carbide blank of the invention provides a cemented carbide (e.g., tungsten carbide-based material that contains cobalt) that does not contain exotic elements additives (i.e., Re, Ge, Ga, Ir, Os, Pd, Ag, Au, Pt, Te, Rh, and Ru) as

additives and does not experience a significant reduction in strength as a result of an EDM process.

[0088] The patents and other documents identified herein are hereby incorporated by reference herein. Other embodiments of the invention will be apparent to those skilled in the art from a consideration of the specification or a practice of the invention disclosed herein. It is intended that the specification and examples are illustrative only and are not intended to be limiting on the scope of the invention. The true scope and spirit of the invention is indicated by the following claims.